AD-A164 275 RESULTS OF THE UCSB FEL ELECTRON BEAM RECIRCULATION EXPERIMENT(U) CALIFORNIA UNIV SANTA BARBARA QUANTUM INST L R ELIAS ET AL. 1983 TR-18 N00014-80-C-0308 1/1

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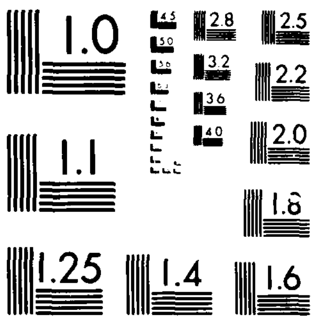

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: No. 18	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Results of the UCSB FEL Electron Beam Recirculation Experiment	5. TYPE OF REPORT & PERIOD COVERED: Technical Report 01/14/82 - 01/13/83
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Luis R. Elias and Gerald Ramian	8. CONTRACT OR GRANT NUMBER(s): N00014-80-C-0308
9. PERFORMING ORGANIZATION NAME AND ADDRESS: University of California, Quantum Institute, Santa Barbara, CA 93106	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61153N; RR011-07-06; NR603-001
11. CONTROLLING OFFICE NAME AND ADDRESS: ONR, 1030 E. Green St., Pasadena, CA 91106	12. REPORT DATE: 1983
	13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified/Unlimited
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Proceedings of the International Conference of Lasers '82, 154, 1983.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Results, FEL, Beam, Recirculation.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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Results of the UCSB FEL Electron Beam
Recirculation Experiment

Luis Elias and Gerald Ramian

Lasers '82

QIFEL018/83

RESULTS OF THE UCSB FEL ELECTRON BEAM RECIRCULATION EXPERIMENT

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Abstract

Experiments demonstrating the generation and recirculation of a high-current low-emittance electron beam through the terminal of a Van Degraph type accelerator are described. Beam emittance approaching the theoretical limit for a thermionic cathode was achieved and a recirculation level of 96% was observed.

Introduction

The UCSB Free Electron Laser project has the objective of producing high efficiency tunable coherent radiation sources suitable for scientific research. Initially, a single stage submillimeter device (currently under construction) and eventually a two stage device, whose parameters are shown in table 1, will be built. A unique feature of both devices is the recirculation of an electron beam through a Van Degraph type accelerator.

Table 1. UCSB FEL Parameters

	Single Stage	Two Stage	
		Pump	Laser
Wavelength	380 microns	600 microns	1 micron
Output power	18 KW	$10^8 - 10^9$ watts/cm^2	~1 KW
Efficiency	50%	50%	1%
Period	3.6 cm	20 cm	600 microns
No. Periods	160	10	1000
Interaction length	5.7 M	2 M	.6 M
Peak magnetic field	500 gauss	20 gauss	200-500 gauss
E. Beam energy	3 MEV	6 MEV	6 MEV
E. Beam current	2 amp	20 amp	20 amp
E. Beam $\Delta E/E$	< .3%	<2.5%	< .05%
E. Beam transverse Emittance	< 15π MM-MR (< 100 norm.)	<43 π MM-MR (<550 norm.)	<4.3 π MM-MR (<56 norm.)
E. Beam max radius in wiggler (Y plane)	2.5 mm	2.5 mm	2.5 mm

From its inception,[1] the success of the program was recognized to be dependent on the generation of an electron beam meeting relatively severe requirements. Some early studies[2] even suggested the existance of fundamental limits on the quality of beam attainable at high currents that would have imposed severe restrictions on the lasers we were proposing — especially the two stage laser where the requirements for low emittance and energy spread is particularly severe.

It was therefore logical to perform our first experiments with the generation and recirculation of an electron beam before attempting actual laser operation.

Experimental Apparatus

Figure 1 is an illustration of the experimental apparatus used during a series of experiments performed between May of 1981 and August of 1982.[3] These experiments were conducted at the facilities of National Electrostatics Corporation in Middleton, Wisconsin using a test accelerator modified for our purposes.

Basically this accelerator consists of:

- A pressure vessel containing 80 PSI of Sulfur Hexafluoride as an insulating gas. This permits electric fields up to 100 KV/CM.
- A polished Aluminum terminal shell on which charge is stored up to 3 million volts potential.
- A set of pelletron chains that carry charge up to the terminal at a rate up to 400 micro-amps.

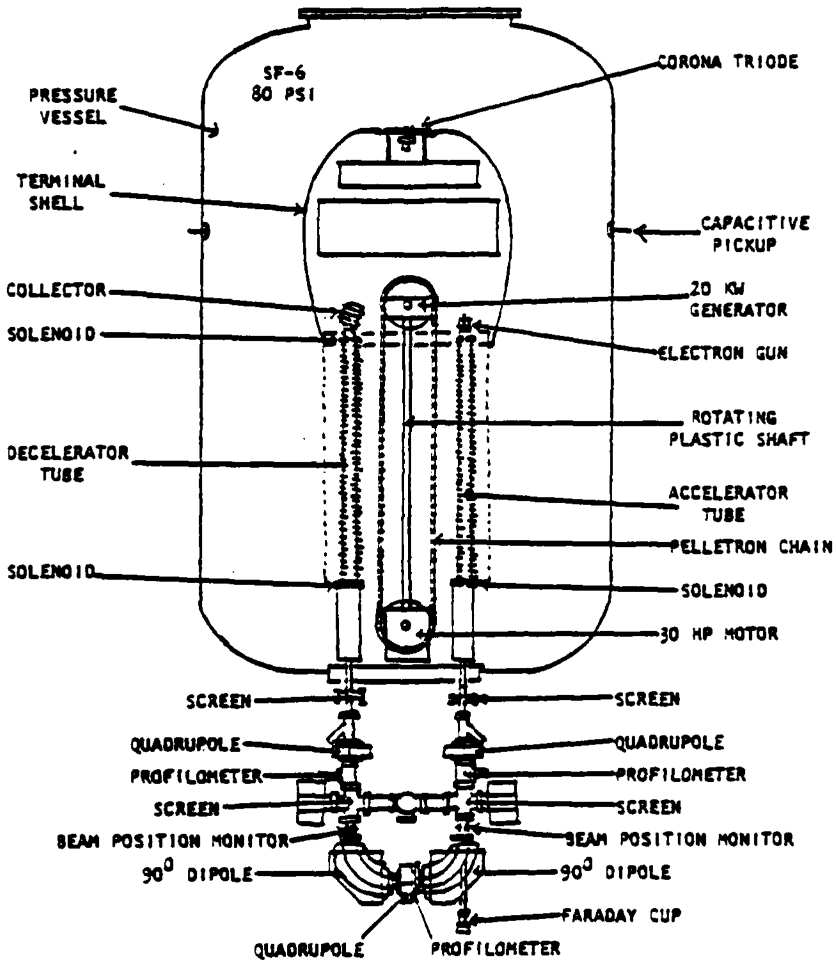

Figure 1. Experimental Set-up.

- A generator within the terminal driven by a rotating plastic shaft and a 30 hp motor providing up to 20 kilo-watts of power.
- A pair of accelerator tubes, one of which is used as a decelerator.

At the top of one tube is an electron gun. It uses a dispenser cathode in a low area compression Pierce geometry It also has an aperture control electrode connected to a high voltage pulse generator for pulsed operation. The gun design was done by William Herrmannsfeldt of S.L.A.C., who expended considerable effort in optimizing its properties. His use of carefully shaped electrodes and minimum focussing fields eliminated most of the spherical abberation normally present in Pierce guns. Construction and testing of the gun were done by Hughes Research. Tests performed on their gun test stand show a normalized emittance of less than 12π MM-MR.

After acceleration, a solenoid and drift space provide phase-space matching to an achromatic transport system that turns the beam through 180 degrees and returns it to the decelerator tube. After deceleration it is received by a multi-stage collector designed by Richard Hechtel of Litton Industries. The collector plates are operated at various positive potentials with respect to the cathode. Power from the generator is used through the collector power supply to boost the electrons back to cathode potential, thus making up the energy lost from the beam.

Beam diagnostics consist of fluorescent screens and profilometer wires at strategic locations around the beam line.

Terminal potential is monitored by capacitive pickup plates located on the pressure tank sidewalls and connected to charge sensitive amplifiers. By monitoring the time derivative of terminal potential, terminal charge and hence collection efficiency can be determined with a high degree of accuracy.

Results

Figure 2 shows photographs taken during recirculation operation. The first photograph shows signals from the capacitive pickups that represent terminal potentials. The upper trace shows the change in terminal potential during pulsing with the electron beam physically interrupted. The lower trace shows the potential with full recirculation. The ratio of the slopes indicates 96% of the electrons being collected.

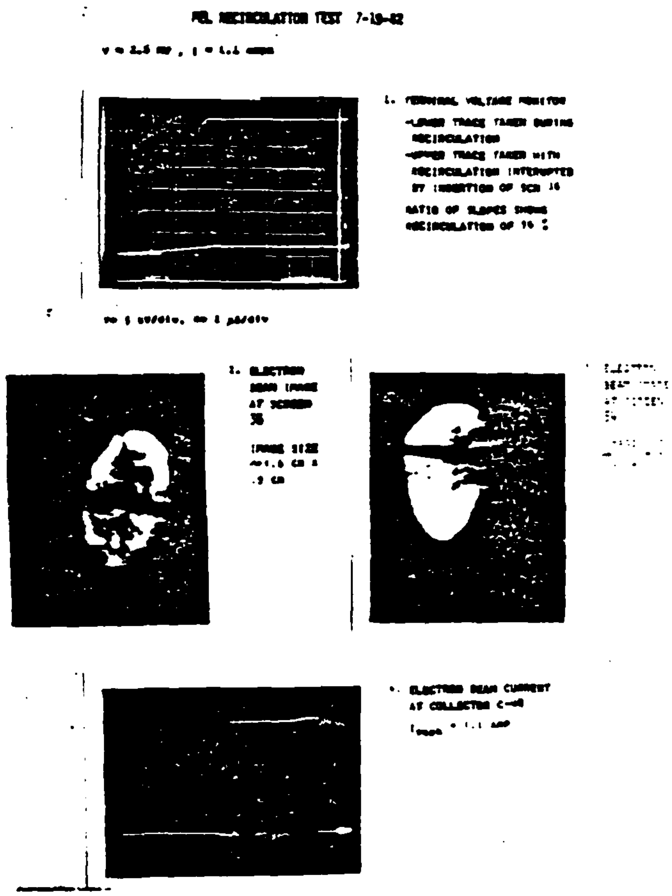

Figure 2. FEL Recirculation test, July 19, 1982.

The second and third photographs show the beam impinging on fluorescent screens just prior to the first 90 degree bend and after being turned around through 180 degrees respectively. A quadrupole upstream restores circular symmetry to the beam before injection into the decelerator tube.

The fourth photograph shows the electron beam current collected in a Faraday cup at the bottom of the experiment. The 1.1 amp, 4 microsecond pulse, with reasonably fast rise and fall times, is typical of the beam used during recirculation.

Table 2 shows the electron beam parameters achieved during the experiments. Fairly consistent and stable 96% recirculation levels were observed but that is not a limit. A few pulses exceeded 99% but were unstable and unrepeatable. We feel that careful alignment, additional shielding of stray AC magnetic fields, and more careful tuning of the apparatus would allow consistent 99% figures.

Table 2. FEL Electron Beam Recirculation Test Results

Beam recirculation		96%
Beam energy		2.5 MEV
Beam current		1.2 amp
Pulse length	w/recirc.	40 μs
	wo/recirc.	4 μs
Period		.5 s
Charging current (limited by Corona triode)		130 μs
Beam emittance*		<2π MM-MR
	Normalized	<12π MM-MR

* Measurement performed by Fermilab-UWM-Harvard group.

2.5 megavolts was the highest terminal potential used because of damage sustained by terminal electronics whenever high voltage arcing occurred. Future improvements in shielding as well as a larger diameter tank at Santa Barbara will permit operation at higher potential.

The increase in pulse length from 4 to 40 microseconds with recirculation demonstrates the importance of recirculation in achieving high duty cycle operation. The rapid discharge of the terminal and gun high voltage power supply by the high current beam limited pulse duration to 4 microseconds in the absence of recirculation.

The .5 second period and 130 microamp charging current were limited by the corona triode characteristics. The corona triode is a field emission device used to regulate terminal potential. Its very non-linear characteristics permitted the regulation of only 130 microamps at the 2.5 MV potential. Operation at 3.0 MV would allow higher current and shorter pulse repetition period.

After completion of the recirculation tests, the experimental apparatus was turned over to a group from Fermilab-University of Wisconsin-Harvard headed by Fred Mills, Dave Cline, and Carlo Rubia to perform an emittance measurement.[4] Their interest in this recirculation scheme stems from the need for a low emittance high current beam for electron beam cooling of protons in future high energy storage rings. Their experiment consisted of a profilometer measurement of the beam envelope at three points just beyond the first 90 degree bend, the first point being a beam waist. Beam emittance and space charge effects can then be unfolded by analysing the beam envelope growth. Their normalized emittance measurement of less than 12π MM-MR indicates an emittance approaching the thermally limited value for a thermionic cathode given by[3]

$$\epsilon_n = 2r\sqrt{\frac{KT}{m_0c^2}}\ , \quad r = 7.6 \text{ MM}$$
$$= 6.8\pi \text{ MM-MR}$$

This expression is for a Gaussian current distribution. The flat-top current distribution of our gain should result in a larger number for thermally limited emittance.

It is worth noting that the Lawson-Penner condition[2] calls for

$$\epsilon_n = .3\sqrt{I}\,\pi \text{ CM-R}\ , \quad I \text{ in kiloamps}$$
$$= .0095\,\pi \text{ CM-R} = 95\,\pi \text{ MM-MR for 1 amp}$$

This is almost an order of magnitude larger than measured. This is not to suggest that the Lawson-Penner condition is wrong. It is an empirical relationship derived from existing accelerators not necessarily optimized for low emittance and is still useful for analysing these types of electron sources.

Conclusion

Our conclusions from these experiments are that:

1. An electron source approaching theoretical thermally limited emittance can be built.
2. A high current beam can be recirculated through the terminal of a Van Degraph type accelerator.
3. The electron beam requirements for a high efficiency high power tunable free electron laser can be met with currently available technology.

References

1. L. Elias, Physical Review Letters 42, 15, 977 (9 April 1979)
2. V.K. Neil, Jason Technical Report JSR-79-10 (Dec. 1979)
3. L. Elias, G. Ramian, Physics of Quantum Electronics 9, 577 (1982)
4. F. Mills et al, IEEE Conference Proceedings, March 21-23, Santa Fe, New Mexico
5. J.D. Lawson, "The Physics of Charged Particle Beams," Clarendon Press, Oxford, 221 (1977).

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